FAULT DIAGNOSIS THROUGH RESPONSIBILITY

Robert Milne

Headquarters Department of the Army
Artificial Intelligence Center
HQDA DAIM-DO, The Pentagon, Wash DC 20310

ABSTRACT

Industry today has a severe problem in the automatic testing of analog cards. At the Air Force Institute of Technology, we are developing an Expert System based on the structure and function of an analog circuit card to drive automatic test equipment. This system uses the information contained in the schematic diagram of the circuit as well as fundamental knowledge of electronics and past experience in maintaining the card. One of the most important aspects of this system is its ability to reason about possible faults based upon the function of the sub-sections of the circuit. This task is accomplished using the type of "second principles" which an electronic engineer would use.

I INTRODUCTION

Testing and fault diagnosis of printed circuit cards is a very important task which is done many times each day. Typically this is performed using pre-determined, static and rigidly structured tests. As a result, the testing tends to be inefficient, missing many faulted components and can often isolate faults to only a large group of components.

We introduce the "theory of responsibilities" as an approach to automated troubleshooting. Using this approach, the understanding of how a circuit works is recorded by assigning responsibilities for parts of the output waveform to subsections of the circuit. These can be assigned manually ro derived from casual simulation.

Our current efforts are directed at automated troubleshooting of analog circuit cards. Our overall system, described in (Milne 1984) and (Ramsey 1984), is designed to automatically test and identify faults in an analog card through the use of automatic test equipment. Our past implementation and papers have conducted testing based on the structural description of the circuit. In this paper, our approach to functional testing is described.

This work differs from others in several significant ways. The work of (Cantone 1985) has been entirely within the structural area. His algorithm for deciding which test to perform based on the most information gained and possible cost is very helpful to structural reasoning, but can't help us once we can no longer probe within an sub-circuit. Cantone only uses structural information to isolate the fault to a single functional area. In this paper, we will show how structural information can be used to further propose faults.

(de Kleer 1983) is working to diagnose faults in analog circuit cards from 'first principles'. That is, given the low level electronic description of how a capacitor works, it should be possible to deduce how a filter would work, and consequently, diagnose faults in it. Although it is agreed that this is the most desirable approach, the author feels that there is too much work still to be done in order to use this approach in testing today. In our work, we start from 'second principles', that is, the type of description that an electronics engineer uses to describes various building blocks of circuits. Several examples are contained below.

(Davis 1983) has done much work in the area of digital troubleshooting based on the function of the components. He relies on computing the function and inverse of each sub-component. In general, it is not possible to compute the inverse of analog functions. Also the digital domain has a very simple output form (1 or 0), while the analog domain may have a very rich signal. Hence different techniques are called for. In fact the more complex output signal is one of the key differences between the analog and digital domains.

The work of (Chandrasekaran 1985) is most similar to our own. He describes the object to be diagnosed in a formal language and then compiles this description into a set of production rules to perform the diagnosis. In our approach, we use a different formal description and four simple rules of diagnosis, rather than compiling the system into production rules. Chandrasekaran's work has not defined a clear role for the interaction of functional and structural reasoning. In our work, structural reasoning plays a dual role. It is first used to isolate the possible fault to a single functional area. Secondly, whenever the output is zero, (giving no information), structural rules are used to propose possible faults.

Qualitative reasoning (Forbus 1981) is important to justify some of our rules and approaches, but since we are working from second principles, many of these results are compiled into the descriptions.

II STRUCTURE

The traditional role of structure is to isolate the possible fault to one functional nodule. The system first checks if the output is correct. If it is not, the path of the signal is traced back through the structure of the circuit and a test is chosen which will split the possible fault path in half. This is done until only one functional module is left.

In our work, structure is also used when the output is zero. In this situation, we have no information on which to base the functional diagnosis, so structural reasoning must be used. In an analog circuit, we are interested in the output current and voltage drop. Their relationship is controlled by Ohm's Law: E=IR. Qualitatively, we can see that if E is zero, then I will be zero; and that if I is zero, then E will be zero. We can also know that if R is zero, then E and I will be zero. Because of the product of IR, if E is zero we will need two rules, since I or R could be zero.

Let us look at voltage. We know that we need an R in order to get a voltage drop. If an output is shorted to ground, then R is zero, and hence no output voltage. We can translate this into a diagnosis rule:

Voltage Short Rule:
 If one component connects the output and ground,
 and the output is zero,
 then that component may be shorted.

We could derive this rule from E=IR, but it can be 'compiled' to the above form. This compilation is similar to (Chandra. 1985) and only needs to be done once for the fault diagnosis system. This rule is an example of the high level knowledge that an electronics engineer may use. We call this an example of a 'second principle'.

From Krichoff's Current Law, we know that the current flowing into and out of a node is zero. If there is no current flowing into a node, then there can be no current flowing out of the node. As before, we can compile these facts into a 'second principle'.

Current Open Rule:
 If one component connects the input and output,
 and the output is zero,
 then that component could be open

We also know that with no current, we will not get a voltage drop. If the output is zero, it could be from no R or no I, based upon Ohm's Law. Because of the dependency between the current and voltage, we cannot be sure, based upon a single zero output, whether we have a short or open, so several hypotheses may be produced.

We will use a simple voltage divider as an example of these structure rules. When the circuit is working properly, the outputs are 01 and 02. Their respective values are determined by the ratio of RI and R2. If the value of 02 is wrong when 01 is correct, then the ratio R1/R2 is wrong. Qualitatively, we cannot tell which value is wrong.

If R1 is a short, then 02 will equal 01 and not be zero. This can be predicted by the application of the Voltage Short rule. (Note that ground being zero is only a special case). If RI is open, then 02 will be zero by the Current Open rule. 01 may or may not be zero depending upon the circuit. If k2 is shorted, then 02 will be zero by the Voltage Short rule. If R2 is open, then 02 will be zero by the Current Open rule.

In this section, we have presented our approach to the use of structure for fault diagnosis. In the traditional way, it is used to isolate a fault, to a single functional module. We also use it to propose faults based upon shorts and opens. These tv/o rules are very powerful and alone will propose the correct fault for most of the examples we have encountered.

III FUNCTION

The Rectifier Circuit:

When the structural rules have isolated a fault to a single functional module, we turn to functional reasoning. To illustrate the theory of responsibilities presented in this paper, a simple rectifierr circuit will be used. In second principles, the rectifier circuit can be described as follows. To build a rectifier circuit, use a diode to convert each peak in the input waveform to a positive output peak. For a typical sine wave, this means two diodes, one for the positive, and one for the negative peak. The output is then filtered. To do this a capacitor is used to store energy and a resistor to drain that energy.

From this description responsibilities can be assigned: each diode produces a peak in the output, one at the positive peak and one at the negative peak. The capacitor charges, giving us the rising ramp, and the resistor discharges the ranp. We can write this formally as:

```
(circuit rectifier        (varies with time t0-t2)
        t0-t1    Output is        Peak at positive-nax
                 by Diodel
        tl-t2    Output is        Peak at negative-max
                 by Diode2
(sub-circuit Peak (varies with time t0-t2)
        tO-tl   Output is         rising ramp
                by Capacitor
        t1       Output is        peak by diodeX
        tl-t2    Output is        falling ramp
                by Resistor
        tl        is at    input-max)
```

The diagnosis rules:

If X is Y by Z and not(Y), then Z is bad.
If X is Y by Z and not(X) then use structure rules.

In this brief paper, the implementation details have been left out, although the PROLOG user will recognise the role for unification.

These are the only troubleshooting rules we need. To diagnose a fault, the output waveform is compared with the input waveform. The first rule will then identify which component is faulted.

The above description was tested on an actual circuit. When the resistor was faulted to the open position, the output was a constant level. Comparing the desired output from the reai output, we are missing the declining ranp, so the resistor is bad. The DC voltage levels are important in this diagnosis, but have been omitted for this paper.

When one of the diodes was opened, the output was missing one of its peaks. By comparing the desired output with the real output and the input, the rule can identify correctly which diode has been opened. V/hen the capacitor is opened, the rising output is not a ramp, so the capacitor is predicted bad. If the resistor is shorted, the output is zero, and the structure rules will correctly propose the fault. It should be note that we are lucky in this case that each component manifests it to a single part of the output waveform. In this brief paper, the voltage levels have been omitted. These are critical to diagnose some faults.

IV DEEP FUNCTIONAL REASONING

In the above sections, we have assumed that we understand how to assign responsibilities between the parts of the output waveform and the components of the circuit. In this section, we will see how this can be derived automatically.

The basic strategy is to simulate the working of the circuit through our 'second principles'. As each component makes a contribution to the overall output, a responsibility is assigned. We then use the above troubleshooting technique to trace the responsibilities to the faulted component.

We will use the rectifier circuit as an illustration. We start with the following second principles:

Diode: If the input is positive, the output equals the input.
Capacitor: A capacitor with a rising input will charge
Capacitor: A charged capacitor with a load, and not a rising input will discharge.
Wire: When two wires meet, the output is the sum of the two inputs.

We also assume low level rules that provide for the addition of signal waveforms, the testing for rising and falling voltage levels and give the voltage across a capacitor. The input to the clipper is in the form of a sine wave from a transformer. When we apply the diode rule, The sine wave is transformed into a postive half-wave followed by zero. The second diode is in reverse polarity, so it produces a zero output followed by a half-wave. Responsibility to each half-wave is then assigned. Next, the two wires add, giving us a half-wave rectified waveform.

How the signal arrives at the capacitor and the input signal is rising. By the capacitor rule, the capacitor now charges. The rise in the output voltage is assigned the capacitor. When the signal stops rising, the capactitor has a load, so discharges. This decreasing output voltage is assigned to the resistor.

In this very brief explanation, we have seen how the v/aveforn gets built up from second principles and the responsibilities are assigned. Using this technique, it is possible to derive the responsiblities from a circuit and then perform troubleshooting based upon these.

V CONCLUSION

In this paper, the "theory of responsibilities" has been outlined. This states that we can perform fault diagnosis by assigning responsibilities for parts of the output to various parts of the circuit. These responsibilities are derived from a casual simulation of the function of the circuit. It has also demonstrated how this works on a typical building block circuit. In our work we have started from 'second principles', that is, the principles which an electronic engineer would use to describes each sub-circuit. This approach has proved to be very effective in diagnosing faults in analog circuits.

If one has only a limited understanding of the circuit, then responsibilities can only be assigned in a limited way, and hence the capability to diagnose faults will be limited. If one has a thorough understanding of the circuit, can do a better job of assigning the responsibilities. However, because of limitations within the domain, it will not always be possible to describe the circuit in such a way as to isolate faults to one component. This limitation, however, primarily comes from the limits of being able to diagnose a circuit as a black box. This technique has been applied to filters, rectifiers, voltage doublers and wave generators. Because of the modularity of most circuits, it works even on seemingly complex circuits, by dealing with the sub-circuits.

Although this technique is very powerful, there is much to be done. It should be possible to derive our second principles from first principles. We have found that we can generally prove the second principles in this v/ay, but we can't do it automatically, yet. A more detailed description of this work is in (Milne 1985).

REFERENCES

[1] Cantone, R. "Model-Based Probabilistic Reasoning for Electronic Troubleshooting", 1JCA1 82, Karlsruhe, Germany, Aug 82.

[2] Davis, R., "Diagnosing Via Causal Reasoning: Paths of interaction and the Locality Principle , AAAI-83, Washington D.C., Aug 83.

[3] de Kleer, J. "AI Approaches to Troubleshooting", Joint Services Workshop on Artificial Intelligence in Maintenance, Oct 83, Boulder, Colo.

[4] Forbus, K. "Qualitative Reasoning about Physical Processes", IJCAI-7, 1981.

[5] Milne, R. "Using AI in the Testing of Printed Circuit Boards", National Aerospace and Electronics Conference, Dayton, Ohio, May 1984.

[6] Milne, R. "The Theory of Responsibilities" SIGART NEWS, July 1985.

[7] Ramsey, J. "Diagnosis: Using Automatic Test Equipment and an Artificial Intelligence Expert System. Dec 84, Masters Thesis, Air Force Institute of Technology.

[8] Sembugarnoorthy, V. and Chandrasekaran, B., "Functional Representation of Devices and Compilation of Diagnostic Problem Solving Systems, to appear in Cognitive Science, 1985.